Project #2 - Internal flow II

MAE 494/598, Fall 2017, Project 2 (12 points)
Hard copy of report is due at the start of class on the due date. As usual, please follow the rules on collaboration. A cover sheet is required.

All tasks are for both MAE598 and MAE494.

Background: A prototype of a mini irrigation system is shown in Fig. 1. It consists of a main pipe and 5 evenly spaced side pipes. All pipes are circular. Figure 1 also shows the cross sections of the apparatus along (i) the plane of symmetry and (ii) a plane perpendicular to the plane-of-symmetry that runs through the axis of a side pipe (e.g., side pipe 1). Water is pumped into the system through inlet "A" and leaves the system through the 5 side pipes and (optionally) outlet "B". This project will quantify how the design of the system affects the mass flow rates associated to the side pipes. Task 2 serves as an example of using Ansys-Fluent to assist the design of an engineering system.

All tasks will seek *steady solution* using turbulence *k-epsilon* model. The density of water is set to a constant 1000 kg/m^3. As usual, please set up the mesh to ensure sufficient resolution for the structure of the flow, particularly near the wall.

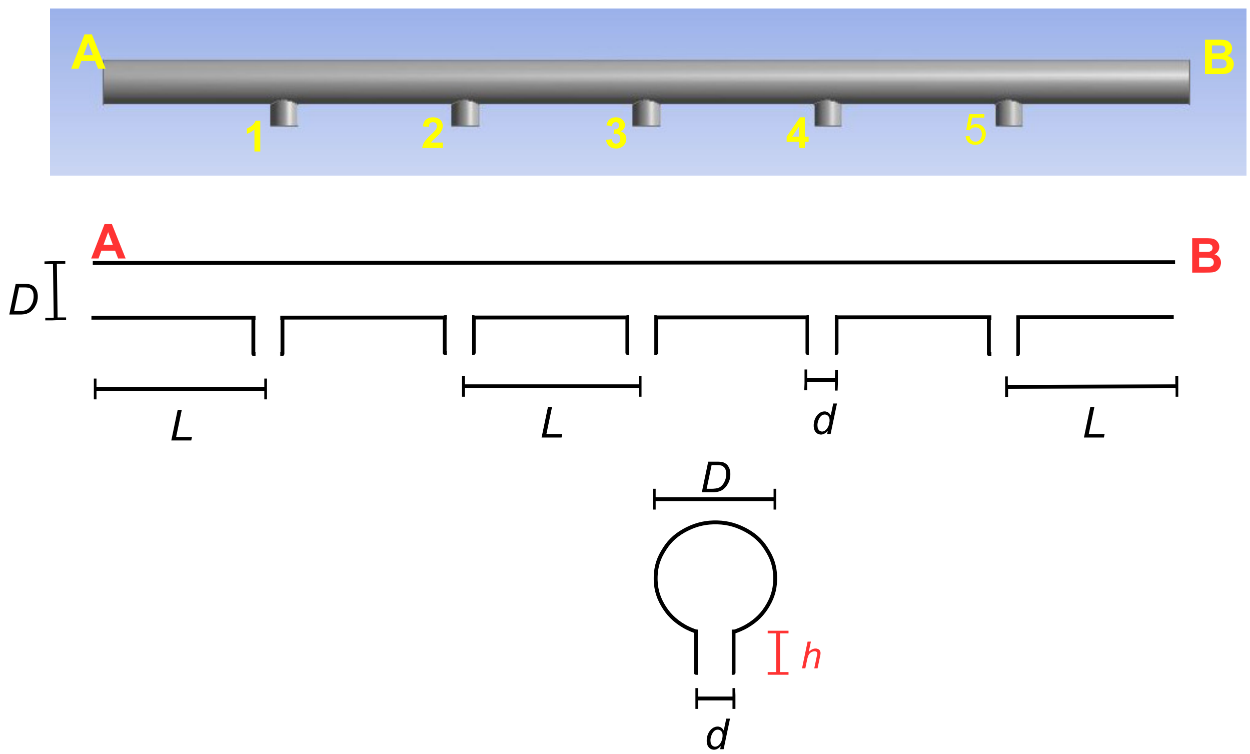

Fig. 1 The geometry of the mini irrigation system (not drawn to scale).

Task 1

Use the design shown in Fig. 1 with L = 50 cm, D = 5 cm, d = 3 cm, and h = 5 cm. (Be aware that L is not the total length of the main pipe but only the spacing between two side pipes. With this setting, the total length of the main pipe, from A to B, is 3 m.) Consider the following 2 cases:

Case (1): Set "A" as a *velocity inlet* with inlet velocity = 0.5 m/s and zero gauge pressure. Set the openings of all 5 side pipes and "B" as *pressure outlet* with zero gauge pressure.
Case (2): Same as (1), except that "B" is no longer an outlet but is completely sealed off (i.e., the right "opening" is now just a wall).

For each case, plot the mass flow rates associated to the 5 side pipes. (For case 1, even though water also flows through outlet "B", do not include that outlet in the plot.) In addition, for each case, make line plots of (i) *static pressure*, and (ii) *the velocity component in the direction of the axis of the main pipe*, along the axis of the main pipe.

Task 2 (This is the key task of the project and is worth 8 points)

From the results of Task 1, one will find that the mass flow rate either decreases monotonically or increases monotonically from side pipe 1 to 5, depending on the design. Suppose that, for some applications, it is desirable to have a uniform mass flow rate across all side pipes. This task asks one to modify the apparatus to make the mass flow rates associated to the 5 side pipes equal, or as close to equal as possible. Using the design in Task 1 as the basis, one is allowed to modify:

(I) The diameters of the side pipes. They can be different for different side pipes. (An obvious constraint is that the diameter of a side pipe cannot exceed the diameter of the main pipe.)
(II) The "area of opening" for outlet B. In Task 1, that outlet is either fully open (Case 1) or fully closed (Case 2). Here, one is allowed to modify the geometry of the opening at B such that only a fraction, between 0 and 1, of the circular disc is open (i.e., through which water can exit the system).

Otherwise, all other conditions must be kept the same as in Task 1: The L and D parameters remain unchanged. (With a change in d, the h parameter can be adjusted slightly to avoid the presence of a kink or discontinuity at the junction of the side pipe and main pipe.) Inlet "A" remains a *velocity inlet* with 0.5 m/s inlet velocity and zero gauge pressure, and all outlets are *pressure outlet* with zero gauge pressure. The outcome of the exercise can be measured by the S index (the smaller it is, the better):

$$S = \frac{1}{M}\sqrt{\frac{1}{5}\sum_{k=1}^{5}(m_k - M)^2} \quad \text{,where} \quad M = \frac{1}{5}\sum_{k=1}^{5} m_k$$ and m_k is the mass flow rate of the k-th side pipe.

(M is the mean of the mass flow rate and S measures the deviation from the mean, normalized by M.)
The deliverables of this task are:

(i) Description of the "best case" (i.e., the one with the smallest S) you obtain, including key geometric parameters (diameters of 5 side pipes; the geometry and fraction of open area for outlet B), mass flow rates of 5 side pipes, the "S" value, and line plots of static pressure and velocity component similar to Task 1.

(ii) Discussions on how you obtain the result. For example, what is your strategy to systematically lower the S value with successive modifications of the design? How do you make the process efficient? If your best design does not produce a uniform mass flow rate, discuss the key obstacles that prevent further improvement of the result. If your conclusion is that it is physically impossible to make the mass flow rates uniform, given the constraints of allowed modifications in (I) and (II), please provide reasons to support your claim.
Note: The discussions are important. Deliverable (ii) accounts for 50% of the credit for Task 2.